Study of the mechanical behavior against horizontal forces of self-supporting facades

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Abstract. The brick facades are one of the most used facades in the current architecture. This typology is used during centuries, but still relevant today. The conventional way to build a brick facade is supporting the outer sheet on the slabs of the building. In buildings with these conventional facades have appeared stability, insulation and sealing problems.

The self-supporting facade appears to solve these problems easily. This type of facade can solve more easily thermal bridges in buildings, which is an optimization of energy consumption. To resist horizontal forces facades need anchors between the two sheets or between the outer sheet and the structure. The current standards in Spain do not define the arrangement of the anchorages between the exterior sheet and the inner sheet of the enclosure. This paper studies the influence of the inner sheet in self-supporting facades. The transmission of horizontal forces between the two sheets of the facade is analyzed in detail, in order to check whether the inner sheet assists in the stability of the outer sheet. Different models of facade have been simulated to compare their results using the finite element method.

Introduction

A large number of existing buildings are constructed with brick facades. This typology has lots centuries old but is still valid. At present, two systems for the construction of brick walls are defined [1]. For one, the conventional facade is defined with air chamber inserted in the structure. In this type both the outer and the inner sheet are supported by the floors. On the other hand, the self-supporting facade is defined with continuous air chamber, wherein the outer sheet passes in front of the slabs. It is a self-supporting wall and is bonded to the structure with connection keys to improve their stability. The Fig. 1 shows these two systems for the construction of brick walls.

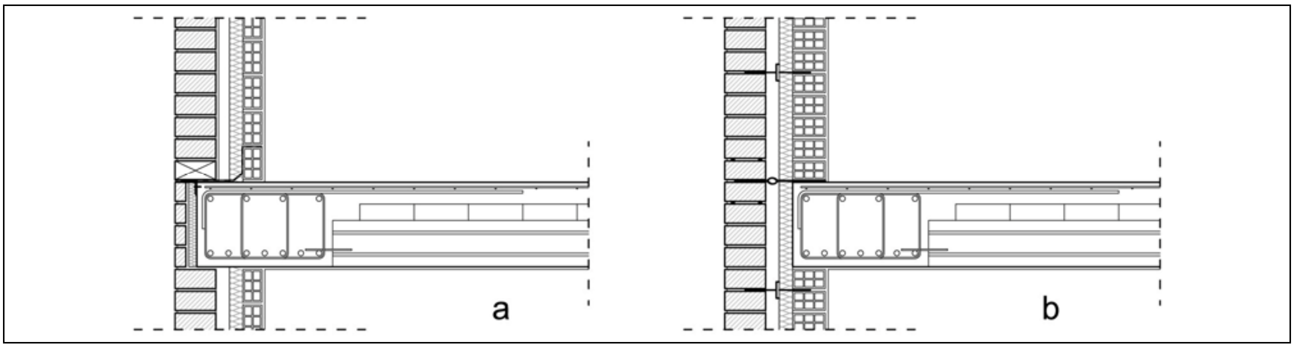

Fig. 1. Conventional facade (a) and self-supporting facade (b).

Conventional facade has an interruption of thermal insulation in each slab, which is a thermal bridge on the fronts of the slabs solved by special pieces [2]. To resolve this problem, the fronts of the slabs are covered with insulation, which usually causes stability problems of the outer sheet. This interruption in the floors also causes possible infiltrations of water in the bottom of the air chamber.

The self supporting facade appears to solve the problems of stability, insulation and waterproofing that can present the traditional enclosure [3]. This facade is formed by a self-supporting outer sheet connected to the structure with metal ties, a continuous air chamber, thermal insulation and an inner sheet. It is an evolution of the English cavity wall. This design allows to cover the building structure with thermal insulating, which prevents thermal bridges and reduces energy consumption.

This type of facade needs fixing elements to transmit horizontal forces. Two types of fixing elements are used in the construction of the facade. The first are the ties that connect the outer sheet with the building structure. The second are the wall ties that connect the outer sheet to the inner leaf in the multilayer enclosures. A Spanish regulation does not consider the cooperation of the inner leaf though it is not supporting wall. These regulations do not indicate the amount of wall ties. The EC6 establishes that the wall ties should be placed by a number not less than 2 keys per m^2 [4]. The French legislation, Unifié Document Technique, establishes that the two sheets of the enclosure should join with anchors separated 60 cm placed staggered in alternate rows [5].

Method

The behavior for the proposed enclosure is performed by the finite element method. The calculation program used to obtain movement and cracking of the facade has been Ansys. This is a finite element software which takes into consideration all types of nonlinearities, plasticizing and breakage. The ANSYS program is a leader in research and has been used for the study of masonry [6] [7]. The modeling chosen for studying the behavior of the enclosure is a 3D macromodelization, with the mechanical characteristics of the brick wall as a whole, not just brick and mortar

The properties of the wall are density, 18 kN/m^3 in the solid brick masonry and 12 kN/m^3 in the hollow brick masonry; Elastic Modulus: 2GPa; Poisson's Ratio: 0.2; Shear transfer coefficient in open crack, 0.25; Shear transfer coefficient in close crack, 0.6; Uniaxial Tensile Strength, 0.3 MPa [8]. The mechanical characteristics of the wall ties are density 78.5 kN/m3; Elastic Modulus: 200 GPa; Poisson's Ratio: 0.3; yield stress 500 MPa. The element type used, called Solid65, is capable of cracking in tension and crushing in compression. The mesh size is 10 x 10 x 4 cm. The thickness of each wall is divided into three layers for better approximation. The inner sheet has restrained the rotation and the elongation in all edges, and the exterior sheet is allowed to rotate and to elongate freely on the top and laterally. The models are loaded by the dead weight and horizontal loads due to the wind action. The wind load increases until the collapse of the model.

Results and discussion

In this paper a part of a self-supporting enclosure where the outer sheet passes in front of the structure is modeled. Three models are compared. In model 1 the outer sheet only has keys to the structure. Models 2 and 3 have keys between the outer and inner sheet. In Model 2, the inner sheet has a thickness of 7 cm. In Model 3, the inner sheet has a thickness of 12 cm. Fig. 2 shows the composition of the three studied facades.

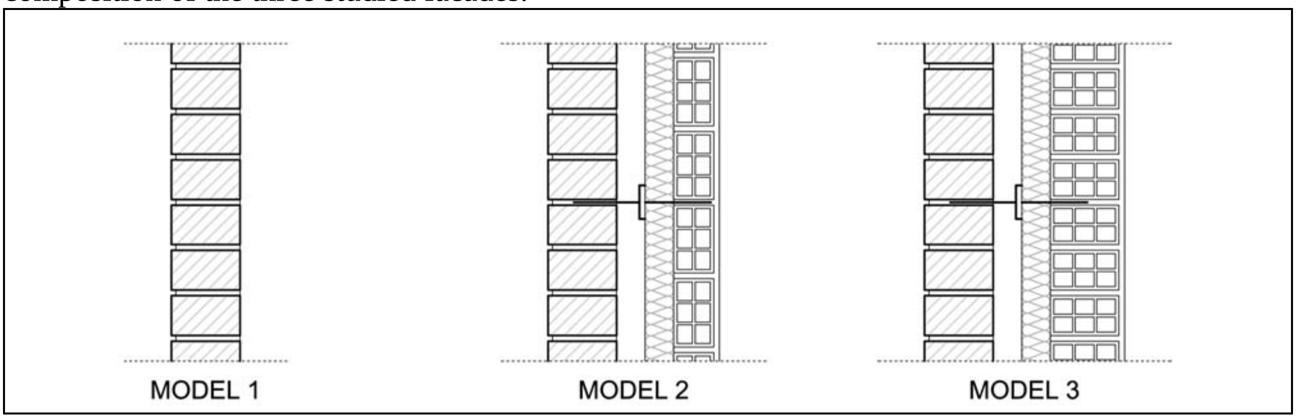

Fig.2. Studied models.

All three models are modeled with the same geometry. It is a rectangular wall, its dimensions are 6.00 m between columns and 2.80 m between floors. The outer sheet of the facade passes ahead by the building structure. This geometry has continuity horizontally and vertically. The outer sheet is connected with metal ties to the building structure. The inner sheet is supported by the floors and pillars. The dead weight is acting on the two sheets and the wind load is acting on the outer sheet. At this point the movement in the axis perpendicular to the facade and cracking are analyzed.

Displacements perpendicular to the facade. The finite element method allows measuring the displacement of every point of the wall. The displacements are reduced by introducing the keys in the sheets. The performance improves when the inner sheet is more rigid. A comparison between the displacements of the center point of the three models is given in Fig. 3. The improvement is clearly seen by the inclusion of the metal ties.

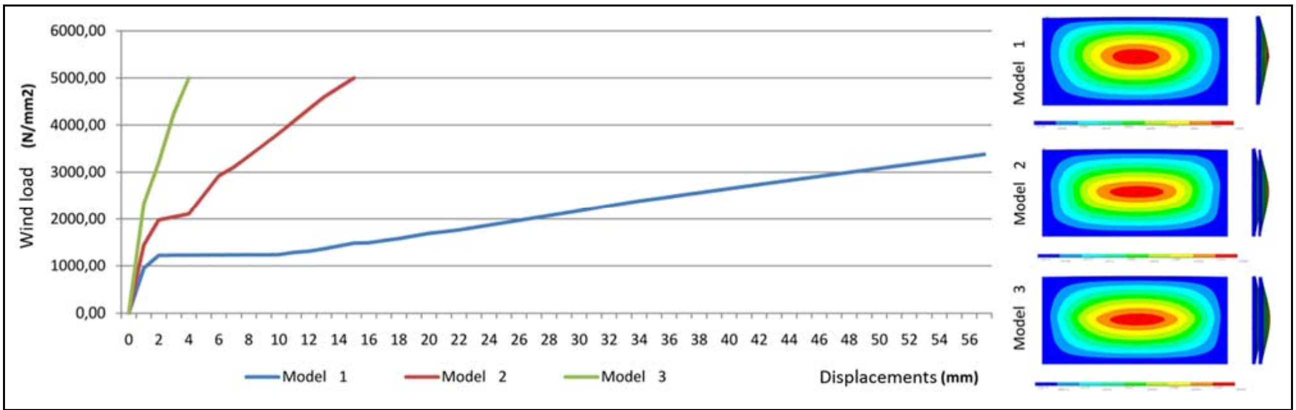

Fig. 3. Pressure/horizontal displacement curve.

Craking. The cracks of the wall start at the vertices and advance with an angle of 45°. As the load increases horizontal cracks which join the first cracks appear. Later the cracks extend on the entire wall. In Fig. 4 the cracking of the three models is shown under a horizontal load of 2000 N/mm^2 and 5000 N/mm^2, higher than the characteristic action values, about 800 N/mm^2. Model 2, with wall ties and an inner sheet of 7 cm thick, shows less cracking than model 1. Cracks appear with a greater load and appear a much lesser extent. Fissures also appear at the junction between the inner sheet and structure. On Model 3, with wall ties and an inner sheet of 12 cm thick, cracking is further reduced. The cracks inclined at 45° disappear completely. In this model, the fissures appear in the middle of the wall and one junction with the building structure. As the stiffness of the inner sheet is increased cracking is more like a conventional facade cracking.

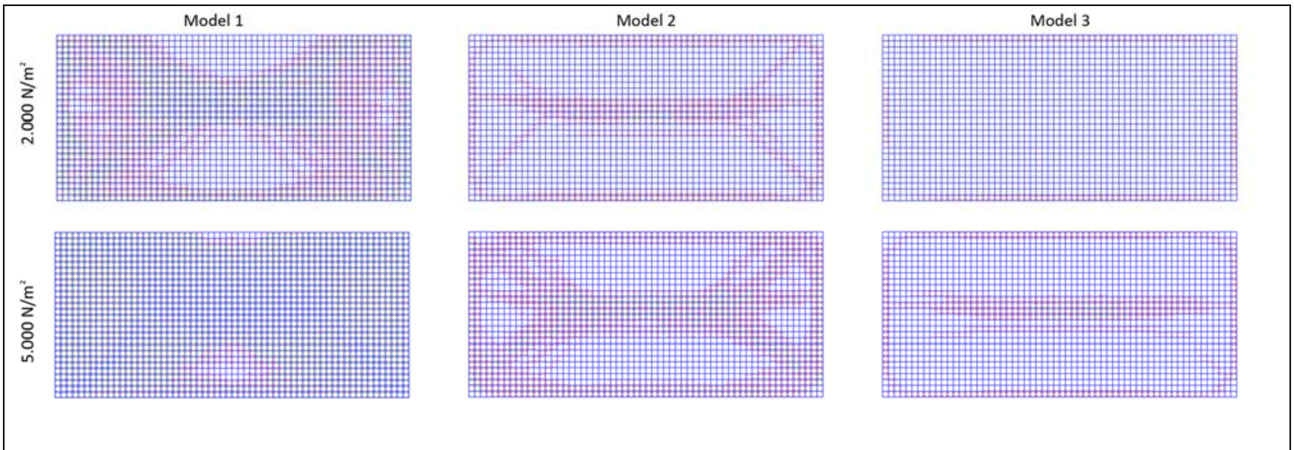

Fig. 4. Cracking in multilayer walls.

Conclusions

The objective of the research is to analyze the non-bearing walls of brick from the point of view of stability and strength to check its correct behavior against horizontal forces. The type of facade studied is the self-supporting wall. This facade prevents thermal bridges and reduces energy consumption.

In the multilayer walls, the joining of the exterior and interior sheets with metal ties improves greatly their behavior in horizontal forces, however the current Spanish legislation does not permit to consider them when checking the facade unless the inner sheet is a bearing wall. The collaboration of the inner sheet when not bearing has been proven with mathematical methods. These metal ties are used to fix the thermal insulation too.

A wall with fixing elements between the two sheets has been modeled, following the recommendations of the French DTU. Comparing a wall with anchorages between the sheets and one without anchors (model 1) shows the effectiveness of the metal ties against horizontal forces. The inner sheet collaborates in the resistance against wind and buckling, decreasing displacement and cracking the outer sheet. Also has been studied the behavior of facades with for different inner leaves. The wall with inner sheet 7 cm (model 2) thick and 12 cm thick (model 3) are compared. The inner sheet 12 cm allows to place the metal ties easier and provides a greater thermal insulation.

The displacements and cracking of the models are studied in this paper. Models with keys to the inner sheet of brick, Models 2 and 3, have lower displacements that model 1. Model 3 with inner brick sheet 12 cm thick has lower displacements than model 2. The cracking patterns of the Model 1 shows a fissure that starts at the vertices and move at an angle of 45°. Model 2, with keys to a brick sheet of 7 cm thick, reduces cracking regarding Model 1. Cracks appear with a greater load and appear a much lesser extent. In Model 3, cracking is further reduced. The cracks inclined at 45 ° disappear completely.

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